π^-/π^+ ratio in heavy ions collisions: Coulomb effect or chemical equilibration ?

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Abstract

We calculate the π^-/π^+ ratio for $Pb + Pb$ at CERN/SPS energies and for $Au + Au$ at BNL/AGS energies using a (3+1) dimensional hydrodynamical model. Without consideration of Coulomb effect an enhancement of this ratio at low m_t is found compatible with that observed in these experiments. Our calculations are based on previous (3+1) dimensional hydrodynamical simulations (HYLANDER), which described many other aspects of experimental data. In this model the observed enhancement is a consequence of baryon and strangeness conservation and of chemical equilibration of the system and is caused by the decay of produced hyperons, which leads to a difference in the total number of positive and negative pions as well. Based on the same approach, we also present results for the π^-/π^+ ratio for $S + S$ ($CERN/SPS$) collisions, where we find a similar effect. The absence of the enhancement of the π^-/π^+ ratio in the $S + S$ data presented by the NA44 Collaboration, if confirmed, could indicate that chemical equilibration has not yet been established in this reaction.

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Recently the NA44 Collaboration has presented results of measurements of π^-/π^+ ratios in heavy ions reactions at the CERN/SPS accelerator at incident beam energies of 158 and 200 GeV/A [1].

The observed excess of negative over positive pions in the low m_t region was interpreted in this report as due to Coulomb final state interactions, although no quantitative estimate of this effect has been given. Important arguments in this interpretation were the following:

(i) RQMD predictions, including the decays of resonances, could not account for this excess.

(ii) in $Pb + Pb$ reactions the effect is more pronounced than in $S + S$ reactions.

In this letter we present a calculation of the pion ratios and of related particle yields using a (3+1) dimensional hydrodynamical model (HYLANDER) [2] for heavy ion collisions at CERN/SPS and BNL/AGS energies. In previous publications on 200 $AGeV$ $S + S$, 158 $AGeV$ $Pb + Pb$ and 11 $AGeV$ $Au + Au$ we described many different physical observables concerning these reactions such as single inclusive spectra and pion correlations (see [3]-[8]). The present calculation is based on these previous simulations, where also resonance decays were taken into account. Since we consider central collisions, we assume axial symmetry around the beam direction.

For the initial conditions of the fireball at SPS energies we had to take into account a certain degree of transparency of the colliding nuclei, whereas for the reaction at AGS energies we considered 3-d full-stopping from the moment of impact (for more details see [3] and [8]).

All the results presented here have been obtained by using an equation of state based on lattice QCD calculations, exhibiting a phase transition from a quark-gluon plasma to a hadronic phase at $T_c = 200 \ MeV$ [2][9]. The freeze-out temperature is chosen as $T_f = 139 \ MeV$.

In our calculations for SPS energies we took into account the detector acceptance as defined in [1] and [10] [1].

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[1]We find, e.g., that only about 17% of negative pions from Λ decay and about 15% of negative pions from Σ decay survive the detection conditions for the $Pb + Pb$ reaction. For the $S + S$ reaction the numbers are respectively 23% and 22%. However, the presented results for the pion ratio are not strongly affected by the

In Fig. 1 we show our results for $Pb + Pb$ and $S + S$ collisions at SPS energies. They are compared to the data published in reference [1]. For $Pb + Pb$ collisions the simulation is compatible with the data (Fig.1(a)), while for $S + S$ collisions (Fig.1(b)) this is not the case: here our model predicts an enhancement as well, which is apparently not present in the data.

In Fig. 2 we show the π^-/π^+ ratio for $Au + Au$ collisions at AGS energies [2]. The results of our simulation are compared with preliminary data from reference [11]. Here the ratio reaches even bigger values than those found for $Pb + Pb(SPS)$ data. Below we will discuss possible reasons for this.

In our model, the low m_t enhancement in the π^- production is a consequence of nuclear stopping, thermalization, hadronization and chemical equilibration of the fireball produced in a relativistic heavy-ions collision. At the beginning, a large number of baryon stopped in the central region will thermalize. This induces a strange chemical potential which favours the production of hyperons (which are not present in the initial state). The number of hyperons reaches a maximum value if the equilibration is complete. After hadronization (freeze-out) the hyperons decay dominantly into $\pi^- + (p, n)$ channels. They are concentrated in the soft m_t region because of the low amount of available kinetic energy in the hyperon decay.

We already analysed the enhancement in the π^- production for $Au + Au$ in [8]. We showed that taking into account baryon and strangeness conservation as well as strangeness equilibration, including the decay of resonances in the final stage, the difference $N_{\pi^-} - N_{\pi^+}$ in our model is determined by the amount of produced hyperons, i.e.,

$$N_{\pi^-} - N_{\pi^+} = N \text{ hyperons decaying into } \pi^- - N \text{ hyperons decaying into } \pi^+ \tag{1}$$

We have [8]:

$$N_{\pi^-} - N_{\pi^+} \simeq 0.64 N_\Lambda + N_{\Sigma^-(1190)} + 0.64 N_{\Sigma^0} - 0.48 N_{\Sigma^+} + 1.64 N_{\Xi^-} + 0.64 N_{\Xi^0} \; ^3 \tag{2}$$

limited detector acceptance.

[2]For more details concerning this simulation cf. [8]

[3]In this simulation we are considering resonances with masses up to 1.5 GeV. About 80% of the enhancement

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On the other hand, if the Coulomb effect would be the main mechanism in the observed excess and the resonance contribution would be of secondary importance, then the total number of π^- should be almost equal to the total number of π^+ and consequently there should appear at large m_t a compensating π^+/π^- excess. This means that the number of pions (or the pion ratio) at large m_t can help to distinguish between these two interpretations. Interestingly enough, up to $m_t - m_\pi = 0.8 \ GeV$ the available $Au + Au$ data do not show an excess of π^+ over π^-. They also show that the total number of π^- is significantly larger than that of π^+. ($N_{\pi^-} - N_{\pi^+} \approx 40$ [11]) (For $Pb + Pb$ no such data are yet avaiable).

We also find that the enhancement of the pion ratio depends on the final baryon density (and therefore on the final baryon chemical potential) of the fireball at freeze-out. The computed baryon density values at freeze out are: 0.072 n_0, 0.094 n_0 and 0.192 n_0 for $S + S(SPS)$, $Pb+Pb(SPS)$ and $Au+Au(AGS)$ respectively [4]. The reduction of the enhancement from AGS to SPS energies can therefore be interpreted as due to an increase of the transparency effect.

One should stress that the K^-/K^+ and $\bar{p}/p$ ratios as predicted by our model do not depend on m_t, in agreement with the results cited in [1]. Furthermore the same approach predicted and/or reproduced correctly the rapidity and transverse momentum spectra of protons and negative hadrons as well as the Bose-Einstein correlations in both $S + S$ and $Pb + Pb$ reactions at SPS energies. In $Au + Au$ at AGS energies it reproduces all single inclusive data (protons, negative and positive pions and kaons).

A possible interpretation of our results for $Pb + Pb$ reactions is that the Coulomb effect is in fact much smaller than expected in [1] and chemical equilibration has to be taken into account as an alternative explanation.

Finally we would like to comment on the fact that our model overestimates the 200 $AGeV$ $S + S$ pion ratio compared to the avaliable data.

of the π^-/π^+ ratio is due to lambdas.

[4]n_0 is the normal baryon density $= 0.14/fm^3$.

In [3] we calculated the lambda production for $S + S(SPS)$ as presented by the NA35 Collaboration in [12]. The multiplicity calculated in our approach was 8.77 and the experimental value was 8.2 ± 0.9 [5].

The overestimation in the pion ratio is surprising in so far as there appears to be agreement between the calculated Λ rate and the measured one (which suggests that a similar agreement might hold for the other, not yet measured, hyperon rates) and this would necessarily imply an excess of produced π^- compared with π^+ (see eq.(2)). However our model is based on the hypothesis of chemical equilibration at freeze-out, and the overestimate of the pion ratio for $S + S$ might indicate that a complete chemical equilibration in this system is not reached until freeze-out, whereas it is in $Pb + Pb$ and $Au + Au$. One expects that the bigger the system or the longer the life-time ($\tau_{(Pb+Pb)} \approx 14 \ fm/c$, $\tau_{(S+S)} \approx 7 \ fm/c$, $\tau_{(Au+Au)} \approx 10 \ fm/c$) [3] [7][8] the higher the degree of chemical equilibration at freeze-out. This would indicate that the π^-/π^+ ratio is more sensitive to the establishment of chemical equilibrium than other physical observables. However we believe that such a conclusion, although extremely interesting and of possible practical value, might be premature, because it strongly depends on the accuracy of preliminary $S + S$ data.

In order to obtain a clarification of the issues raised above the following experimental steps appear necessary:

(a) Determination of all accessible hyperon rates in $S + S(SPS)$, $Pb + Pb(SPS)$ and $Au + Au(AGS)$ reactions.

(b)Measurements of the π^-/π^+ ratio at large m_t in all three reactions.

(c) Remeasurements of the π^-/π^+ ratio in $S + S(SPS)$ at low m_t.

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[5]The NA35 Collaboration presented in a later paper [13] a new value for the Λ total multiplicity: 9.4 ± 1.0. In this experiment the Σ^0 were detected together with the Λ, so as in our calculation presented in [3].

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Figure Captions

Fig. 1: π^-/π^+ ratio obtained from a (3+1) dimensional hydrodynamical simulation (HY-LANDER) in comparison to the data from ref.[1], (a) for $Pb + Pb$ collision and (b) for $S + S$ collision. Both cases refer to CERN/SPS energies.

Fig. 2: π^-/π^+ ratio obtained from a (3+1) dimensional hydrodynamical simulation (HY-LANDER) in comparison to the data from ref. [11] for $Au + Au$ collision at BNL/AGS energies.
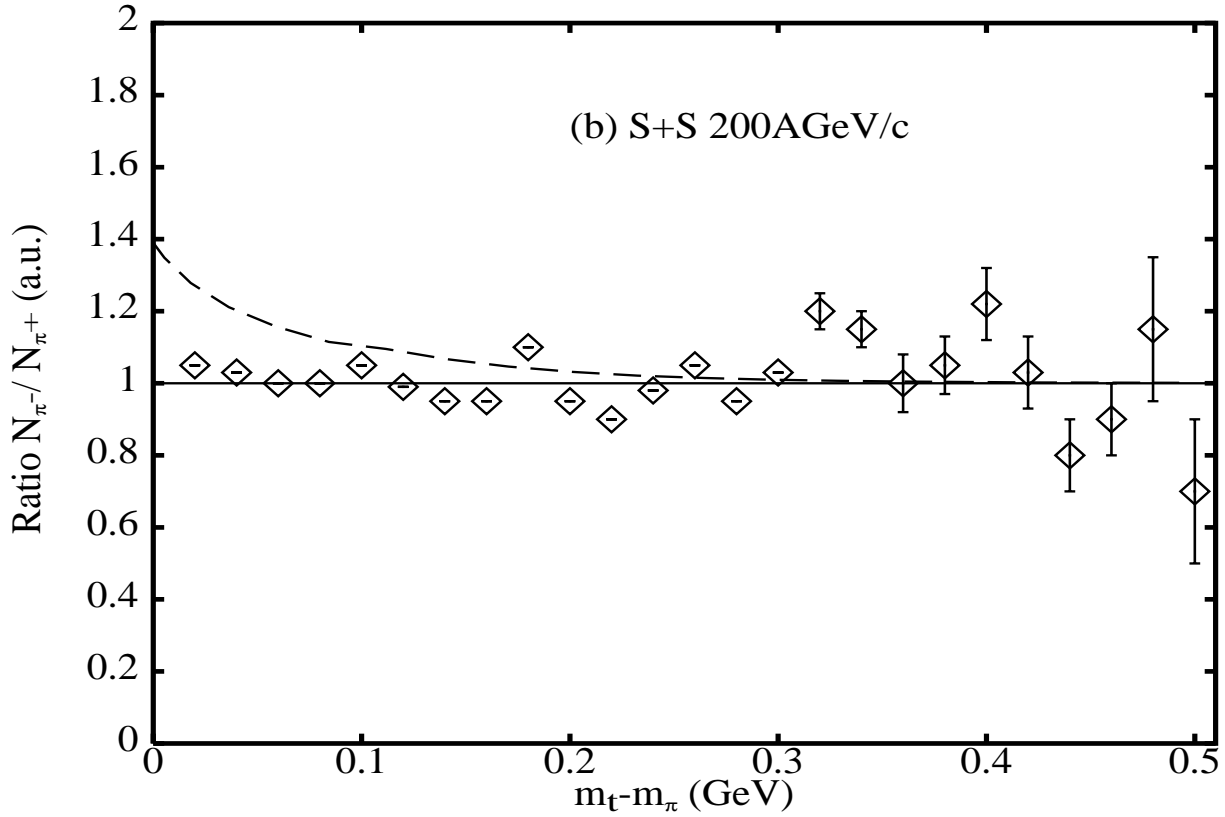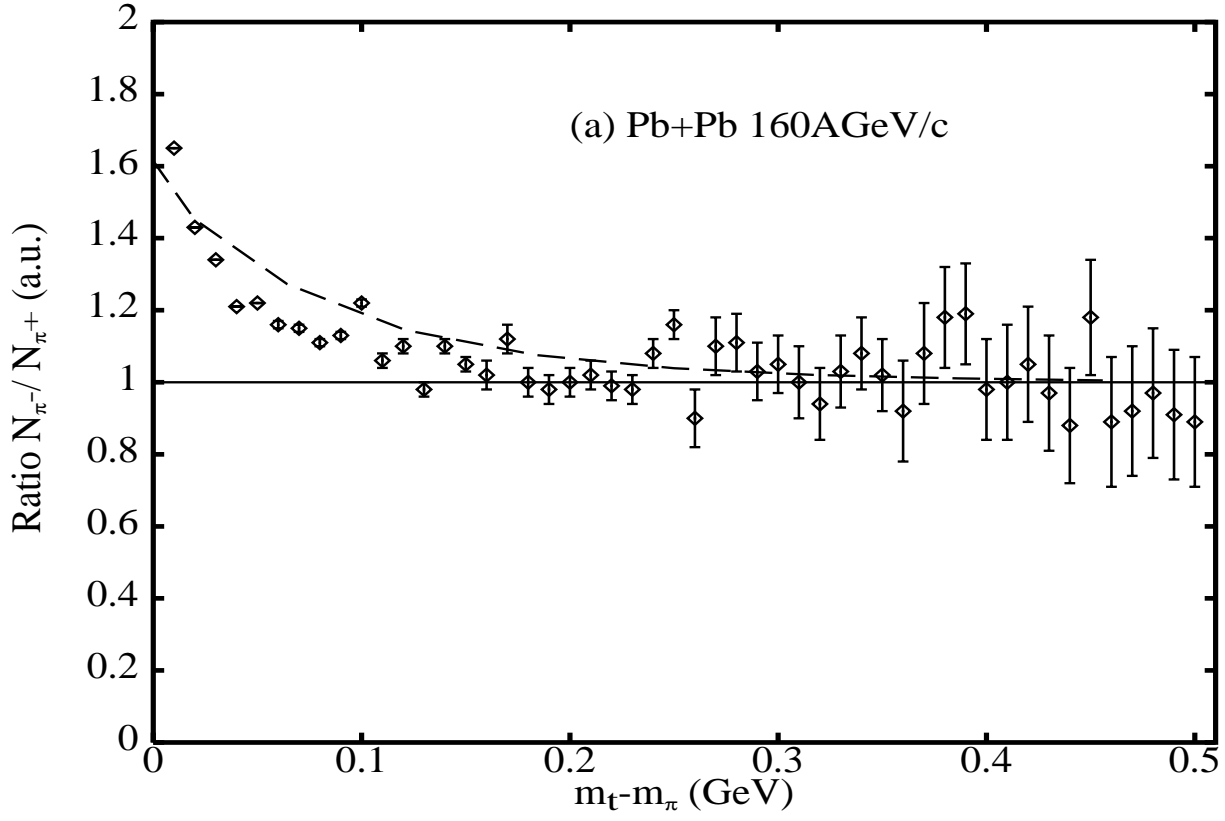
FIGURE 1

FIGURE 2